AN INTELLIGENT CAD SYSTEM FOR INTEGRATING THERMAL AND FORM-MAKING ANALYSIS

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Abstract. This paper presents an intelligent CAD system for integrating morphological and thermal considerations involved in the making of architectural form. A shared knowledge base is at the core of the proposed system. The system is designed to allow independent modules that target the different aspects of a building design and analysis (e.g., thermal analysis, and morphological analysis) to access and modify the knowledge contained in this knowledge base. The paper discusses the structure of the system and issues pertaining to its implementation. An example of the use of the system is illustrated. Conclusions and findings about the utility of the system are drawn.

1. Introduction

In architecture, form is the common denominator of all the factors that influence a design. A change in the state of one of these factors modifies the morphological structure of the design, which in turn, will affect the state of all other factors. As a way of understanding the underlying rules and structures of architectural form, yet without limiting creativity, form-making studies aim to enhance the competence of architects by: (1) furthering their understanding of the structure of architectural form (i.e., its morphology) and of the nature of its attributes and determinants (e.g., the requirements of commodity, firmness, and delight) and (2) building tools that aid designers to explore and evaluate their form-making decisions both systematically and effectively.

Walls, columns, and floors are the basic elements that constitute architectural form. In a plan, walls and columns are the two basic elements of architectural vocabulary. The locations of walls in relation to each other and to the columns define architectural spaces. The location of walls and columns in a plan is determined by its underlying geometric structure or parti. The designer's knowledge of architectural morphology goes beyond the mere arrangement of

such elements. Designers have the ability to consider design at multiple levels of abstraction and to translate efficiently between their interpretations. They can see designs in terms of the adjacency relationships that constitute the arrangement of spaces. As well, they make associations between the relative sizes of the spaces, their locations, alignment, and proportions to derive higher order compositional principles such as symmetry, balance and hierarchy. Moreover, they can interpret designs in terms of their behavior whether this is structural, thermal, and acoustical, among others.

The development of a design from a sketch to final stages takes into account several processes of refinement by utilizing external media or simulating and representing the intermediate stages. Current CAD systems do not have support for such processes that allow integration (Eastman, 1994). Recently, knowledge engineering that emerged from the field of artificial intelligence (AI) has been utilized to solve such problems by focusing on specific areas such as large systems integration, and generative systems, among others (Flemming et. al., 1994; Gero, 1996; Phol, 1990). Knowledge representation and search are two fundamental issues for building AI systems. Knowledge representation involves representing concepts and their relations that belong to a domain area into a well defined framework of syntax and semantics that allows complex problem solving. Search provides the mechanisms and control structures that works on the knowledge represented to discover relevant solutions. In addition to utilizing both concepts into a single environment, this paper describes a system that incorporates emerging object linking and embedding technologies (OLE) under the Windows environment. The paper describes the overall structure of the system as well as its implementation. In addition, the paper provides an example of the use of the system and discusses the findings.

2. The Integrated CAD System

The system consists of a sketch pad, a computer vision module, a morphology module, a thermal analysis module and a shared database, Figure 1. The sketch pad module reads pixel-based images and allows the user to modify their properties. It also supports image processing operations such as noise reduction through median filtering. The computer vision module works on representations created or opened using the sketch pad module and allows the user to extract the vector data of these images. In addition, this module structures the extracted information in a form that is compatible with the grammar module and the thermal analysis module. The morphology module includes evaluation and interpretation components. Some of the evaluation components that are implemented include corner, wall, and room detection. The interpretation component includes grammatical inference (i.e., interpretation of spatial structure) which is based on universal shape grammars
(Emdanat, Vakalo, and Malkawi, 1996), symmetry and hierarchy evaluations. The thermal analysis module uses the Transfer Function Method (Stephenson and Mitalas, 1967). This procedure is based on response factors and the interplay of heat exchange between various surfaces and sources of heat gain.

The system is organized around a shell that contains the overall description of the building. The shell is designed to make the most use of object-oriented programming techniques. This includes schema representations that allow object inheritance and hierarchical class structure to be modeled. The underlying hierarchical class structure of the shell captures the dependency relationships between the elements of a building and their properties (Vakalo, Malkawi, and Emdanat, 1996).

The overall vision of the system framework is being designed to allow the user to input the design in two ways, by drawing it or scanning it through the editor. As soon as the user draws or scans the design, the system processes this information through the vision module. When the user is finished using the editor to draw and sketch the design, the vision module will be activated and several operations will take place. The module will allow corner detection, wall detection, opening detection and room detection. In addition to the topological information about the building, the output of the vision functions will be

Figure 1. The System Structure.
forwarded, indexed and stored in the shell’s internal representation. If the user is scanning an image, the module will convert the pixel based images into a vector based format and store its topological information as well as the information output from the vision module. As the information is being indexed and stored in the shell, the user can request several evaluations and simulations to be conducted. Several morphological evaluations can be made including symmetry detection and hierarchy detection. In addition, thermal, lighting and acoustic simulations can take place. The outcome of this evaluation and simulation is then channeled back into the shell to be indexed and stored. As a result, the shell will expand its knowledge base. This knowledge base is then utilized in building the artificial intelligence component. Expert systems will access this knowledge base and use their own search methods and knowledge bases to provide advice and criticism about the building.

3. Implementation

Currently, the implemented components of the system include a user interface, a morphology module, a thermal simulation module and a shell. The user interface contains a sketch module, as well as, evaluation and display functions, Figure 2. As soon as a sketch is completed, it will be sent to the morphology module to detected its elements. At this point, corner, wall and room detection will be conducted and the information will be stored in the shell’s internal representation as objects. This information can then be viewed by the user and displayed through the interactive interface. At this stage, the user can request to evaluate the current sketch they are designing by selecting the evaluation function within the interface and using what has been detected from the building components. The evaluation functions are connected to both the morphological and thermal modules. In the morphological module, the interpretation functions will be activated to interpret spatial structures, symmetry, and hierarchy. In the thermal module, cooling, heating and room temperatures can be evaluated. The information from this evaluation is then stored and indexed in the shell’s internal representation and can be channeled back into the interface to be displayed if the user asks for it.

Communications between the shell and its modules as well as with other CAD applications such as AutoCAD are accomplished through Object Linking and Embedding (OLE). OLE is an application integration technology that can be used to share information among applications within the Windows environment. OLE allows maximum utilization of existing code modules. It enhances the potential of collaborative work both in designing and implementing large computational systems. The system is being designed as a set of functions that allows external communication with stand-alone objects.
The system is being written for the MS Windows 95/NT environment and is implemented using VB 4.0 and Visual C++ 4.2 utilizing OLE automation.

4. An Example

Using the system, designers can access and modify the attributes of a particular design element interactively and observe the changes it would engender on the overall design performance. Alternatively, designers can modify some of the evaluative criterion (i.e., the thermal comfort measures of a particular space) and the shell will identify the problematic areas. This will result in a better understanding of the emerging design solution and its performance which, in turn, will allow users to make more intelligent form-making decisions.

As an illustration of the use of the system as an analysis module, a building was selected. It was modeled in AutoCAD r.13 (see Figure 3-A) and then translated into the system. The computer vision module was used to analyze the morphological structure of its plans. Spatial information was extracted and recorded into the shared database that is maintained within the shell of the main module. This information includes corner, wall, and room detection. Part B of Figure 3 illustrates the original plan of the image turned into a raster-based (i.e., a bitmap) representation to be used in this module. The first operation is to recognize the walls. The pixels that make up the plan are expanded (Figure 3-C) to plug the openings. Then the plan is reduced back to its original size. The
result of this operation is a representation of the plan that contains only the walls (see Figure 3-D). A pixel difference operation (Terzidis, 1994) is then carried out on the original plan and the one shown in Figure 3-D to obtain the openings. At this stage the boundary of the plan is detected (Figure 3-E) and used for room detection. This is done by applying the pixel difference operation between that and the plan shown in Figure 3-D.

The detected information is now stored in the shell database and the user can view this information through the interface (see Figure 4). In addition to this, the user has several options to evaluate. For example, when the user chooses to evaluate the spatial structure of the building, the system will display its analysis.

Figure 3: The vision Module.

Figure 4: Building Morphological Properties.
pertaining to the corner conditions (Figure 5-B,C,D) and the adjacency relationships among the rooms (see Figure 5-E,F).

![Diagram of a building with corner conditions labeled B, C, D, E, and F.]

Figure 5. Example of the Use of the System.

To evaluate the design thermally, the shell provides the user with an intuitive interface to assign non-geometric properties to the extracted elements of the design. Information about the location and orientation of the building is entered through the interface. The user can also click on an element and modify the properties associated with it. This is established by utilizing the vision module’s detection that has already been stored in the shell’s internal representation. For instance, if the user double clicks on a wall, a space, or an opening, the system retrieves all the information from the database about the selected element and displays the appropriate properties dialog for the user. Figure 6 shows the material properties dialog of a wall or a wall or a set of walls.

After all the properties are assigned, the user can choose to run the thermal simulation to check the thermal performance of the building. Figure 7 illustrates the room temperatures and their associated thermal loads. At any time the user can ask for morphological or thermal analysis and the system will display an instant feedback.
5. Conclusions

The system in its elementary stages demonstrates the advantages of OLE in complex computer aided design systems. The modularity of OLE and its internal structure has allowed the integration of independent modules that specializes in different aspects of the design problem. Breaking the design process into these modules allows for the study of their effects independently
and in relation to other modules. Although testing of the independent modules for collaborative and conflict avoidance methods has been conceptually investigated.

When fully implemented, the system will provide a computer-based environment that allows designers to test their ideas robustly. It is envisioned that further development and use of the system will generate insights into the relationship between architectural form and its determinants.

References


